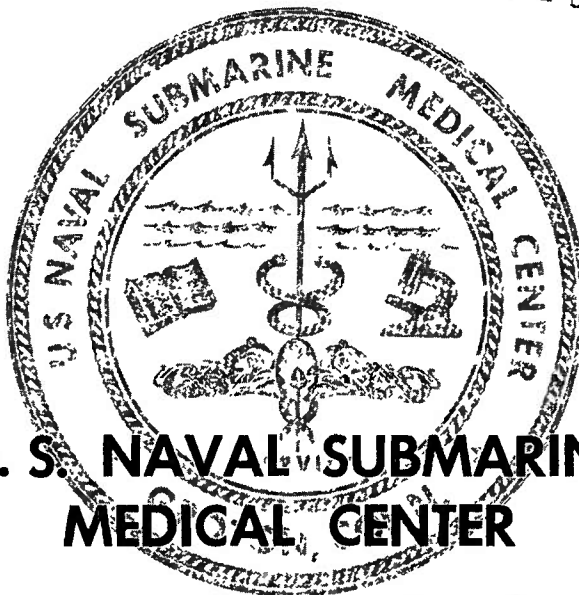


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# U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NUMBER 529

AUDITORY FATIGUE FOLLOWING TONE-BURST TRAINS AT 2.2 KC

by

J. Donald Harris, Ph.D.

Bureau of Medicine and Surgery, Navy Department  
Research Work Unit MF022.01.04-9004.09

Approved and Released by:

Gerald J. Duffner, CAPT MC USN  
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Naval Submarine Medical Center

28 May 1968

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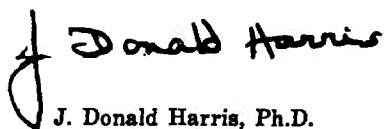
SUBMARINE MEDICAL RESEARCH LABORATORY  
NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 529

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Investigator:

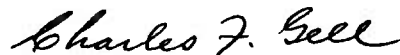
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## **SUMMARY PAGE**

### **THE PROBLEM**

To predict the deleterious effect on human hearing of listening to high-energy acoustic pulses at 2200 cycles per second.

### **FINDINGS**

Graphs and mathematical formulae are provided to predict significant temporary hearing losses as a function of sound pressure level, pulse duration, pulse rate, and overall time of listening.

### **APPLICATION**

The Damage Risk Criterion presented can be used to specify the acoustic habitability of workspaces ensonified with such pulses.

### **ADMINISTRATIVE INFORMATION**

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF022.01.04-9004—Optimizing of Special Senses in Submarine and Diving Operations. The present report is No. 9 on this Work Unit. It was approved for publication on 28 May 1968, and designated as Submarine Medical Research Laboratory Report No. 529.

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## ABSTRACT

Three hundred and two sailors were exposed by phones in groups of 11-20 men to 2.2 kilocycle/sec (kc) pulses (5 msec rise-fall time) of 37-250 msec pulse duration at 105-120 dB sound pressure level, duty cycle (on-time/total time) from 0.1—100%, and for 5-120 min/session. Permutations were selected to throw direct light on the four stimulus variables and on their interactions as well. Pulse-tone audiometry by magnetic tape was accomplished 7 times in 6 min at 2.5, 3, 4, 6, and 8 kc, before and immediately after exposure. The concept of a criterion temporary threshold shift (TTS) was developed in which one Kryt represents the area of TTS plotted on an audiometric chart from 2-8 kc. Any TTS can then be expressed in terms of the Kryt. Thus, for each of our subjects, for each of seven audiograms taken approximately once per minute, we have seven successive Kryt values. When plotted over recovery time, these values can be compared to the area enclosed on the graph representing one Kryt lasting for two min; this summation datum is termed the Nox.

Mean Nox values for each experimental condition were determined. Within our data, (1) each 5 dB SPL adds 0.5 Nox; (2) pulse duration as such is negligible; (3) each log session duration adds 0.65 Nox; and (4) the Nox is a linear function of duty cycle.

Subjective and, to some extent, objective observations lead us to set a damage risk criterion of two Nox for pulsed stimulation at 2.2 kc. Graphs are provided by which any combination of stimulus parameters which would yield two or more Nox may be predicted.

# AUDITORY FATIGUE FOLLOWING TONE-BURST TRAINS AT 2.2 KC

Very many studies on auditory fatigue have explored certain parameters of the fatiguing stimulus. This has been accomplished to some extent for pure tones and for noises of various bandwidth, both continuous and intermittent. Unfortunately, the shorter tonebursts, and the smaller duty cycles (on-time/total time) have not been well sampled. This laboratory covered these conditions (Harris, 1959) for a stimulus of 3.5 kilocycles (kc), but confined attention to the temporary threshold shift (TTS) (always in decibels (dB)) at 4 kc. Some preliminary observations led us to the unhappy conclusion that predictions of TTS from a 2.2 kc stimulus could not be made as precise as desirable from the earlier data at 3.5 kc. It was therefore decided to complete observations at 2.2 kc, using a variety of parametric combinations, checking for the effect of each parameter separately and in interaction.

The parameters of interest include individual tone-burst duration, sound pressure level (SPL; in this experiment SPL is always computed in dB from .0002 microbar), duty cycle (on time/on and off time), and overall exposure duration.

a. **Tone-Burst Duration.** Ward, et al (1958) derived an equation for recovery of TTS:

$$TTS_t = TTS_{2min} (1 - 0.37 \log_{10} \frac{t}{2})$$

where  $t$  = any interval after stimulus exposure cessation; but they pointed out that for burst durations shorter than 250 milliseconds (msec), or longer than 1 min, the equation might not—probably would not—hold. No equation predictive of TTS exists for tone-burst durations of less than 250 msec.

b. **SPL.** Experiments too numerous to list show TTS to be a linear function of SPL. This is expressed in the equation of Ward, et al (1958) for white noise stimulation:

$TTS_{2min}$  at 4 kc = 1.06 duty cycle (SPL-85)  $\log_{10}$  Stimulus Duration/1.7, provided  $TTS_{2min}$  is less than 50, and stimulus duration is at least five minutes. Harris (1967) has shown the generality of this equation form for con-

tinuous pure tone stimulation, the constants differing with frequency.

c. **Duty Cycle.** The equation of Ward, et al, above, shows TTS to be a linear function of duty cycle. This was in general corroborated for tone-bursts at 3.5 kc (Harris, 1959), but considerable uncertainty exists for the very small duty cycles. The data of Selters and Ward (1962), for example, were confined to the 50 percent duty cycle and to noise-burst durations of 30 seconds and longer. For high-intensity clicks, the duty cycle is a function of click rate; Ward (1962) showed that interclick intervals of 1-9 sec yield the same TTS after 60 clicks each, but that if as much as 30 sec elapses between clicks, TTS is less, especially at 4 kc as compared with other frequencies, and especially for the earlier recovery process R1 (see Hirsh and Bilger, 1955). Evidently the smaller duty cycles must be studied with some care. Differential effects of frequency, of recovery processes, and of middle ear muscle activity may all exist.

d. **Overall Exposure Duration.** Almost complete unanimity exists that TTS is proportional to log exposure duration; but with high-intensity clicks at 25/min, Ward, et al (1961) found it proportional to linear time. Evidently this matter must be looked into in any particular set of stimulus parameters.

As a consequence of these considerations, it was deemed advisable to create stimulus conditions incorporating a broad range through each of the four parameters listed here: tone-burst durations 37-250 msec; SPL 105-120; duty cycles 0.1—50% and 100%; session duration 5-120 min. Our practical purpose was to explore the borders of permanent damage for brief, high-intensity tonebursts at 2.2 kc, and to write damage risk criteria (DRC) for such acoustic conditions.

A word must here be said as to the index of TTS. Many writers have noted by audiometry that 4 kc is earliest and hardest hit by acoustic insult; and in our earlier paper using 3.5 kc tone-bursts we confined ourselves to studying TTS at 4 kc. However, with stimu-

lation at 2.2 kc it seemed likely that frequencies lower than 4 kc would also be affected, perhaps even more profoundly affected. Furthermore, as is well known, the frequency of maximum TTS may change with stimulus SPL; and Van Dishoeck (1948) showed that after 100 dB SPL at 1 kc, the frequency of maximum TTS changed from 2.8 kc after one min stimulation to 1.4 kc after five minutes. We therefore felt it necessary, to present a true picture of TTS and its recovery, to sample several frequencies from 2.5—8 kc, and several times each within the first few minutes of recovery. Thus our index of TTS must condense information much in excess of the usual  $TTS_{2 \text{ min}}$  at 4 kc.

## METHOD

### Subjects.

In this laboratory, young healthy males 18-25 yrs old are available in quantity for a few hours each, but cannot be detailed for many successive days. This fact dictated our experimental design. Subjects were selected in groups of 8-20, but usually 12, from a 50-man squad, as having no audiometric loss (ASA, 1951) greater than 10 dB at any frequency through 8 kc. There were 26 such groups. Although at the upper limits of fatigability, significant subjective discomfort was produced, in general all subjects were cooperative; none asked to be excused.

### Apparatus and Procedure.

a. **Workspace and phones.** A double-wall soundproof room lined with acoustical tile was used, seating 20 men. Each arm chair was provided with two Permoflux PDR-8 phones in MX cushions. The 40 phones had been selected from among a larger number, with a National Bureau of Standards 9-A coupler, Western Electric 640AA microphone and SPL meter, as not deviating from the mean phone by more than 3 dB at each of the frequencies 2, 3, 4, 6, and 8 kc. All left ear phones were wired in a parallel circuit, and all right phones in another.

b. **Stimulus Creating TTS.** The output of a General Radio Model 1304 oscillator, set to 2.2 kc with a Hewlett Packard Model 500A frequency meter, was led to a Grason-Stadler switch, timer and attenuation pad, then to an

Altec Model 1569A amplifier, and finally switched to one of the phone circuits.

The phone exhibiting median output at 2.2 kc was fitted to the 9A coupler, and the voltage to that phone yielding 105-120 SPL were noted for continuous tones. The Grason-Stadler electronic switch was adjusted to a rise-fall time of 5 msec, and set at either 37, 70, or 250 msec duration (measured at the frequencies representing half power), or set to the continuous mode when called for by the design. These conditions were checked with a Tektronix oscilloscope.

For group stimulation, then, a 2.2-kc tone either interrupted or continuous, was presented to each subject's L or R ear, at some duty cycle at some SPL, for 5-120 min. These conditions, and the number of ears involved, are in Table 1.

For duty cycles, 4 SPL's, 3 tone-burst durations, and 3 session durations, there are 324 permutations, an impossible and unnecessary experimental design. Table I shows that each stimulus parameter was sampled in a fashion which allowed it to vary while other parameters were changed in any of several ways. Thus, interactions could be spotted early in the experiment, and a sort of sequen-

TABLE I — GROUPS AND NUMBER OF EARS GIVEN EACH EXPERIMENTAL CONDITION

| DUTY CYCLE | SOUND PRESSURE LEVEL     | 37-MSEC TONE-BURST  |          | 70-MSEC TONE-BURST                         |          | 250-MSEC TONE-BURST |                         |
|------------|--------------------------|---|----------|--|----------|---------------------|-------------------------|
|            |                          | MINUTES   | DURATION | MINUTES                                    | DURATION | MINUTES             | DURATION                |
|            |                          | 5   | 25       | 5  | 25       | 5                   | 25                      |
| 0.1%       | 110<br>115               |   |          | YLI 20<br>WLI 19                           |          |                     |                         |
| 0.5        | 110<br>115               |   |          | VRI 20                                     |          |                     |                         |
| 1.0        | 110<br>115               |   |          | AAR 11<br>VLI 20                           |          |                     |                         |
| 1.5        | 110<br>115<br>120        | AL 12<br>KR 12  | HL 12    | TR 20<br>FL 12                             | SL 8     | XR 16               | GR 11                   |
| 3.0        | 110<br>115               |   |          | YRI 20<br>WRI 19                           |          |                     |                         |
| 5.0        | 110<br>115               |   |          | BBL 15<br>WRI 19                           |          |                     |                         |
| 10.0       | 105<br>110               | IRI 12  |          | JR 12<br>EL 11<br>AL 11                    | PR 12    |                     | DR 12                   |
| 10.0       | 115<br>120               |   | OL 12    | ML 12<br>IR 11<br>VLI 20<br>RL 12          |          | LL 12               | IL 11                   |
| 25.0       | 105<br>110<br>115<br>120 | MR 11<br>NL 12<br>PL 12                                   | FR 12    | ER 11<br>BR 15<br>VRI 20<br>JL 12<br>RL 12 |          | LR 12               | GL 11<br>RR 12<br>OR 12 |
| 50.0       | 110<br>115               |   | UR 17    |  |          |                     | CL 12                   |
| Contin.    | 110<br>115               | 5 MIN - AR 12, 25 MIN - BR 11 and YLI 20<br>5 MIN - UL 17 |          |  |          |                     |                         |

c. **Pre-Exposure Audiogram.** A magnetic tape was prepared and played back on an Ampex 300-2C unit, which yielded 7 audiograms on each ear at 2.5, 3, 4, 6, and 8 kc within a total of 6 min 2 sec. A total of 35 items (5 frequencies, 7 audiograms) for judgment was presented in that interval. Each item consisted of 6 tone-bursts, 500 msec on, 500 msec off, in descending 5-dB steps. The subject crossed out on his answer sheet (see Table II) the number of spurts he heard at each item. The initial tones at each frequency were recorded at levels dictated by the differential acuity across frequency for normal ears, while the 6-burst item allowed a range of 25 dB to be studied. Instructions and item naming came to the contralateral phone. The timing of the seven audiograms is shown in Table III.

In deriving the pre-exposure audiogram for an individual ear, the seven items at each frequency were averaged to the nearest decimal.

d. **Post-Exposure Audiograms and TTS Computation.** Immediately after a stimulus session was terminated, the phone circuit was switched from the amplifier to the tape playback and the tape started. Twelve seconds later, Item A at 2.5 kc was begun, and 55 sec later the 8-kc pulses of Item E completed one audiogram; by 108 sec a second audiogram had been completed; and so on.

| NAME | GROUP | EAR | DATE | TIME OF DAY |
|------|-------|-----|------|-------------|
|------|-------|-----|------|-------------|

**Audiogram**

| I   | A | 0 | 1 | 2 | 3 | 4 | 5 | 6 | B | 0 | 1 | 2 | 3 | 4 | 5 | 6 | C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | D | 0 | 1 | 2 | 3 | 4 | 5 | 6 | E | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|-----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| II  | F | " |   |   |   |   |   | G | " |   |   |   |   |   | H | " |   |   |   |   |   | I | " |   |   |   |   |   | J | " |   |   |   |   |   |   |   |   |   |   |
| III | K | → |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| VII | ↓ | → |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

For each ear separately, for each frequency

The problem at this point evolved into one of finding a way to compress a broad-frequency audiometric loss into a single number. This problem was met with the concept of the cri-

| <u>Audiogram</u> | Frequency in Kilocycles/Second |            |            |            |            |
|------------------|--------------------------------|------------|------------|------------|------------|
|                  | <u>2.5</u>                     | <u>3.0</u> | <u>4.0</u> | <u>6.0</u> | <u>8.0</u> |
| I                | 12                             | 22         | 31         | 39         | 49         |
| II               | 60                             | 69         | 81         | 92         | 102        |
| III              | 113                            | 124        | 134        | 145        | 155        |
| IV               | 166                            | 177        | 187        | 197        | 208        |
| V                | 217                            | 226        | 237        | 247        | 257        |
| VI               | 267                            | 277        | 288        | 299        | 309        |
| VII              | 320                            | 331        | 342        | 351        | 362        |

terion TTS. Following in general a proposal of Working Group No. 46 of the NAS-DRC-Armed Forces Committee on Hearing, Bioacoustics and Biomechanics (Kryter, et al, 1966), an audiometric loss approaching social significance is one of 10 dB hearing level (HL) at 1 kc, 15 at 2 kc, or 20 at 3 kc and higher. This loss, expressed as an area on an audiogram chart, we call a Kryt, from the original Greek Kriterion; plural Kryter.

Each group stimulated produced seven audiograms as in Table IV; these were separately plotted on semilog paper where 5 dB = 1 inch and the distance 1-2 kc = 1.5 inch. The seven areas representing TTS at the successive testing intervals were then integrated and each divided by the area representing one Kryt.

TABLE IV  
MEAN TTS IN DECIBELS FOR A TYPICAL STIMULUS EXPOSURE

| Audiogram No. | Midpoint in Recovery Time | Frequency in Kilocycles/Second |      |      |      |      |
|---------------|---------------------------|--------------------------------|------|------|------|------|
|               |                           | 2.5                            | 3.0  | 4.0  | 6.0  | 8.0  |
| I             | 31                        | 16.4                           | 15.5 | 17.0 | 12.5 | 12.0 |
| II            | 81                        | 11.0                           | 14.5 | 10.8 | 11.0 | 14.0 |
| III           | 134                       | 8.5                            | 15.0 | 10.5 | 5.0  | 6.0  |
| IV            | 187                       | 6.0                            | 13.0 | 7.0  | 4.8  | 3.8  |
| V             | 237                       | 6.0                            | 11.5 | 11.2 | 6.0  | 8.0  |
| VI            | 288                       | 3.0                            | 7.0  | 8.2  | 5.5  | 6.0  |
| VII           | 342                       | 4.0                            | 9.0  | 6.5  | 6.0  | 4.5  |

It was then necessary to compress a set of Kryt values, usually growing successively smaller, into a single number representing total effect of stimulation over the 6-min recovery interval. This problem was met with the concept of the criterion Nox. A value of one Nox represents a Kryt lasting unchanged for a two-minute period. The Kryt values for each group as in Table IV were graphed over time with coordinates linear in Kryter and in time, and the total area enclosed for each group was expressed with respect to the area enclosed by 1 Nox.

In sum, each group furnished a set of seven Kryter converted to a Nox, which expresses total damage at all relevant frequencies for the total recovery period studied.

e. **Adjusting Tape Levels and Computing Post-Exposure Audiogram.** It was not always possible to predict accurately how intense the

tone-burst sequences should be so that the best man would not hear all six pulses at least one frequency at some recovery time, while the poorest man would hear no pulses at any time at some frequency. In order to utilize such men, and to allow for extensive TTS under some conditions, we had recourse to two procedures:

(1) If we had occasion to believe that the stimulus would yield, on the average, about 30 dB TTS in the first minute, but drop to about 15 dB after 5 min, the tape level for audiograms No. I and II would be set 30 dB above the pre-exposure level, 24 dB for No. III and IV, 18 for No. V and VI, and 12 for No. VII. From the protocols the experimenter could reconstruct the level of each post-exposure item relative to its 7 pre-exposure mates, and easily compute TTS for any frequency at any recovery interval.

(2) There were cases where judgment was faulty, or where ears differed widely in response. In these cases, as where at, say 3 kc, the first 3 responses were "O" pulses, the TTS for that ear was interpolated from a joint consideration of the TTS at adjacent frequencies plus the extrapolation backward in time from the graph of the ear's TTS at 3 kc at recovery intervals IV—VII.

In no case was an individual's data thrown out of his group altogether; but in a few cases where the levels had been set too weak, or in a few cases, too loud, so that there were not at least 8 men in the group needing no such treatment, the whole group was thrown out and the stimulus repeated, the tape level adjusted on the basis of direct experience.

## RESULTS AND DISCUSSION

### 1. The Effect of SPL.

Fig. 1 gives the Nox values for five sets of conditions, varying each only with SPL. The predicted linear effect of SPL is seen, increasing about 0.5 Nox for each 5-dB increase in SPL, for all of the conditions sampled. There is no indication here of any interaction between SPL and any other stimulus parameter.



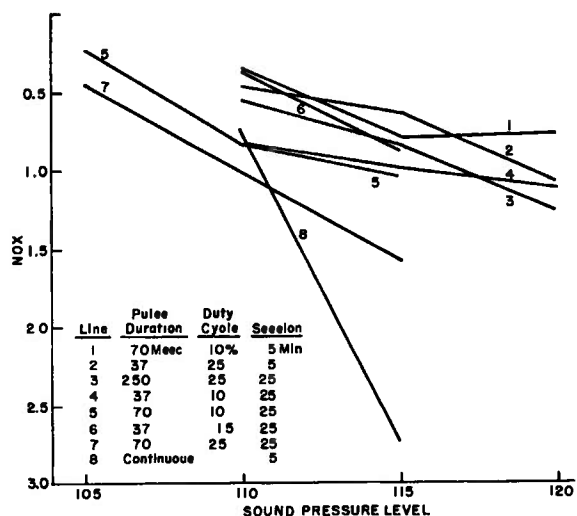


Figure 1. — Effect of Sound Pressure Level on Temporary Threshold Shift (About 0.5 Nox/5 dB)

## 2. The Effect of Pulse Duration.

Fig. 2 gives the data for seven sets of conditions, varying each only with pulse duration. Pulse duration as such is seen not to be an independent variable, inasmuch as the average slope of these seven lines is about zero.

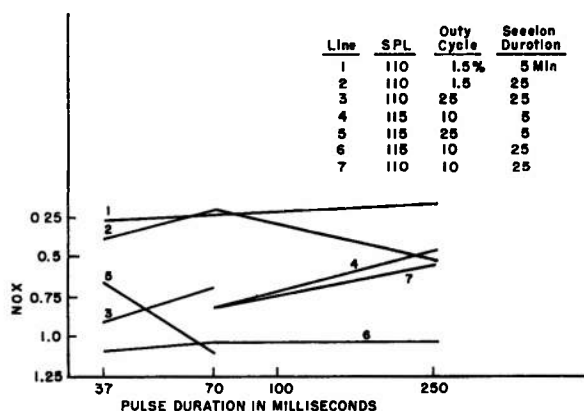


Figure 2. — Effect of Pulse Duration on Temporary Threshold Shift (TTS) (Negligible)

This result recalls a conclusion of our earliest study at 3.5 kc (Harris, 1959) in which it was found that equal total energy yielded equal TTS; for example, five min of stimulation yielded constant TTS, no matter whether this 1) was continuous, 2) was 1200 pulses of 250 msec duration, or 3) 60,000

pulses of 5 msec duration (inter-pulse interval was always 333 msec.) In Fig. 2, each line represents a constant duty cycle, and thus constant energy. The equal-energy hypothesis thus is seen to hold at least over the range of duty cycles 1.5 - 25%

Another approach to the equal-energy hypothesis can be found in comparisons between pairs of groups given different pulse durations but proportionately different duty cycles. For example, of two groups given 115 SPL for five min, one had 70-msec pulses at 10% duty cycle, the other 37-msec pulses at 25%, or nearly the same total energy; the former yielded .80, the latter .65 Nox. If pulse duration per se were operating, the Nox values should have been approximately 2:1. However, the conditions chosen for this experiment were not such as to pursue further this line of attack.

## 3. The Effect of Session Duration.

A number of opportunities were created to explore the effect of session duration. Fig. 3 shows seven sets of conditions, including continuous stimulation at 110 SPL; conditions within each line vary only in session duration. A fairly regular tendency is seen toward a linear slope of about .65 Nox/log duration. No evidence of interaction is seen.

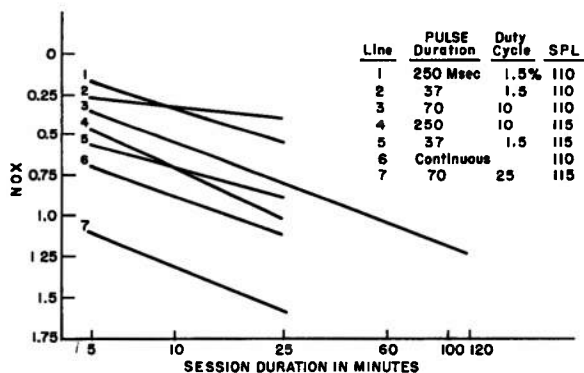


Figure 3. — Effects of Session Duration on TTS (Linear Effect with Log Duration)

## 4. The Effect of Duty Cycle.

Fig. 4 gives the data on TTS vs duty cycle, collapsed over pulse duration. Each point represents one or more groups; each line represents a set of conditions, varying only with duty cycle. A rather sharply accelerating function is seen for log duty cycles up to

50%. Graphed in linear coordinates, this curve would be linear with duty cycle. However, the data for continuous tones (100% duty cycle) are not well predicted by extrapolation; although the absolute Nox values, and the trend of the effect of duty cycle through 50%, are very similar both for stimulation at 110 SPL for 25 min and 115 SPL for 5 min, so that Line 2 in Fig. 4 approximates both sets of data, nevertheless continuous stimulation at 115 SPL for 5 min is much more noxious than 110 SPL for 25 min.

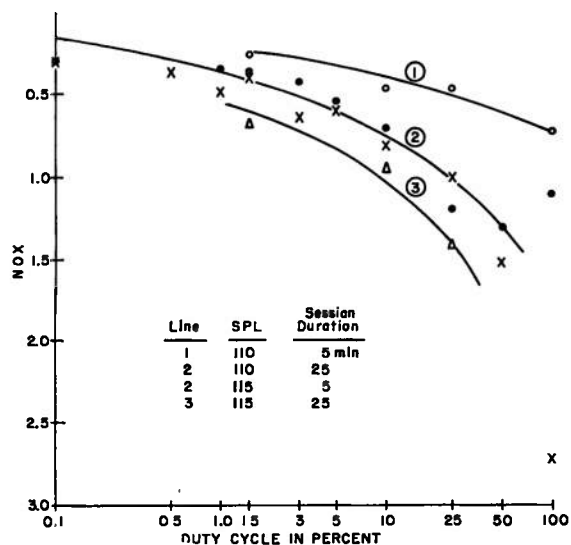


Figure 4. — Effect of Duty Cycle on TTS (Linear Effect)

## 5. Relations Among TTS, KRYT, and NOX.

It may be of interest to note from our data whether the concepts of the Kryt and of the Nox have had a virtue over and above what we might have expected from the conventional use of the 4Kc TTS<sub>2</sub> as an index of incipient damage. We have correlated the seven Kryter one at a time with the Nox, and the 4 Kc TTS .5-6 min also with the Nox. The results are in Table V.

Column "Nox" gives the *r*'s between the final Nox value for each group vs the Kryt values. This indicates that the Kryt values at recovery times 1.3-2.2 min are the best predictors of final Nox.

Column "4 Kc" gives the *r*'s between the Kryt values at each recovery interval vs the TTS at 4 kc at the same recovery interval. This indicates that the Kryt values and the TTS at 4 kc are best related at the 1.35-min

recovery period, but that perhaps 40% of the variance associated with Kryter cannot be explained by variance of TTS at 4 kc.

An  $r=.92$  was found between the Nox vs the TTS<sub>2 min</sub> at 4 kc, over all groups. If there is an advantage, it is in favor of the Kryt. There exist in our raw data many instances of loss greater at 3 kc than at 4 kc, as could be expected from the use of a 2.2 kc stimulus frequency; and in these cases the 4 kc TTS would overlook these significant losses, whereas the Kryt does not. Furthermore, there exist many groups for which the recovery curve of Dryter over time does not show the regularity called for by the general formula for this event. In this case, the Nox concept can encompass these perturbations and better summarize the total effect than TTS at any one frequency at any one recovery time is able to do.

Columns labelled "A" in Table V give the *r*'s between the total Nox value for each group, vs each of the seven consecutive values of TTS at each frequency. These columns indicate that there is little to choose among recovery intervals of TTS in predicting final Nox values.

Columns labelled "B" give the *r*'s between the TTS at 4 kc for each of the recovery intervals, vs the TTS at these intervals for each of the other frequencies. This indicates that the TTS<sub>2 min</sub> at 4 kc correlates well (of the order of .8-.9) with the TTS at successive recovery intervals for the lower frequencies, but at 6-8 kc for the *r*'s are quite appreciably lower (of the order of .4-.6).

Columns labelled "C" give the *r*'s between the TTS at successive recovery intervals for each frequency, vs the total Kryt value at each recovery interval. This indicates again that the total Kryt values are best predicted by the 3-4 kc data, but that the higher frequencies also influence the variance among Kryt values.

We conclude that although the Kryt and Nox values are (necessarily) strongly related to the more traditional 4 kc TTS values, they do offer additional information and a way to compress such information into a single usable number.

TABLE V

PEARSON  $r$ 's BETWEEN SELECTED MEASURES OF TTS

| Kryt Value<br>At Recovery<br>Interval: | Frequency in Kilocycles Per Second |     |     |    |    |     |    |    |     |    |    |     |    |    |     |    |    |
|--|------------------------------------|-----|-----|----|----|-----|----|----|-----|----|----|-----|----|----|-----|----|----|
|  | NOX                                | 4KC | 2.5 |    |    | 3.0 |    |    | 4.0 |    |    | 6.0 |    |    | 8.0 |    |    |
|  |                                    |     | A   | B  | C  | A   | B  | C  | A   | B  | C  | A   | B  | C  | A   | B  | C  |
| I                                      | 87                                 | 76  | 81  | 87 | 78 | 90  | 91 | 80 | 85  | 91 | 79 | 62  | 62 | 63 | 42  | 52 | 33 |
| II                                     | 91                                 | 82  | 83  | 89 | 76 | 90  | 95 | 84 | 90  | 90 | 83 | 63  | 62 | 68 | 54  | 50 | 44 |
| III                                    | 91                                 | 79  | 81  | 86 | 69 | 83  | 85 | 78 | 83  | 86 | 74 | 43  | 32 | 51 | 49  | 43 | 44 |
| IV                                     | 87                                 | 73  | 78  | 78 | 65 | 88  | 84 | 66 | 87  | 91 | 79 | 67  | 59 | 66 | 56  | 54 | 54 |
| V                                      | 88                                 | 74  | 82  | 80 | 67 | 86  | 86 | 80 | 71  | 77 | 76 | 71  | 66 | 69 | 58  | 57 | 48 |
| VI                                     | 83                                 | 68  | 82  | 83 | 74 | 76  | 73 | 75 | 89  | 89 | 86 | 56  | 43 | 68 | 62  | 52 | 57 |
| VII                                    | 85                                 | 52  | 84  | 85 | 78 | 74  | 74 | 75 | 89  | 90 | 83 | 65  | 63 | 65 | 60  | 58 | 55 |

Column Notes: Nox: Final Nox Value for Each Group Vs the Seven Kryt Values

4 KC:  $TTS_{2 \text{ min}}$  at 4 KC Vs Kryt Value at Each Recovery Interval

A: Final Nox Value for Each Group Vs TTS at Each Recovery Interval

B:  $TTS_{2 \text{ min}}$  at 4 KC Vs TTS at Other Frequencies at Each Recovery Interval

C: TTS at Each Frequency at Each Recovery Interval Vs Germane Kryt Value

## 6. Damage Risk Criterion (DRC) in Terms of Nox.

In absolute terms, our data show that one or two men will have hearing symptoms (tinnitus, excessive TTS, prolonged recovery) which begin to give some personal concern when the mean Nox value is over 2.0. This corresponds on our correlational worksheet to a mean 4 kc  $TTS_{2 \text{ min}}$  of 20-25 dB, with and occasional ear showing 40+ dB. We therefore have come to feel that a properly conservative DRC for laboratory studies is any combination of stimulus parameters at 2.2 kc which yields 2+ Nox. Of course, if stimulation were an octave above or below 2.2 kc, this figure for DRC might well not hold.

Figs. 1-4 may be entered to determine, by the extrapolations suggested, what combinations of pulse duration, SPL, duty cycle, and session duration may be utilized without exceeding DRC.

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| 13. ABSTRACT<br>Three hundred and two sailors were exposed by phones in groups of 11-20 men to 2.2 kilocycle/sec (kc) pulses (5 msec rise-fall time) of 37-250 msec pulse duration at 105-120 dB sound pressure level, duty cycle (on-time/total time) from 0.1 - 100%, and for 5-120 min/session. Permutations were selected to throw direct light on the four stimulus variables and on their interactions as well. Pulse-tone audiometry by magnetic tape was accomplished 7 times in 6 min at 2.5, 3, 4, 6, and 8 kc, before and immediately after exposure. The concept of a criterion temporary threshold shift (TTS) was developed in which 1 Kryt represents the area of TTS plotted on an audiometric chart from 2-8 kc. Any TTS can then be expressed in terms of the Kryt. Thus, for each of our subjects, for each of seven audiograms taken approximately once per minute, we have seven successive Kryt values. When plotted over recovery time, these values can be compared to the area enclosed on the graph representing 1 Kryt lasting for 2 min; this summation datum is termed the Nox.<br><br>Mean Nox values for each experimental condition were determined. Within our data (1) each 5 dB SPL adds 0.5 Nox; (2) pulse duration as such is negligible; (3) each log session duration adds 0.65 Nox; and (4) the Nox is a linear function of duty cycle.<br><br>Subjective and to some extent objective observations lead us to set a damage risk criterion of 2 Nox for pulsed stimulation at 2.2 kc. Graphs are provided by which any combination of stimulus parameters which would yield 2 <sup>+</sup> Nox may be predicted. |  |  |                      |

## KEY WORDS

**LINK A**

**LINK B**

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## Auditory Fatigue

### Temporary Threshold Shift

### Damage Risk Criteria

## High Energy Sonar Signals